Detector Systematics and Weak Lensing

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Goal

Keep shape changes due to detectors below systematic limit

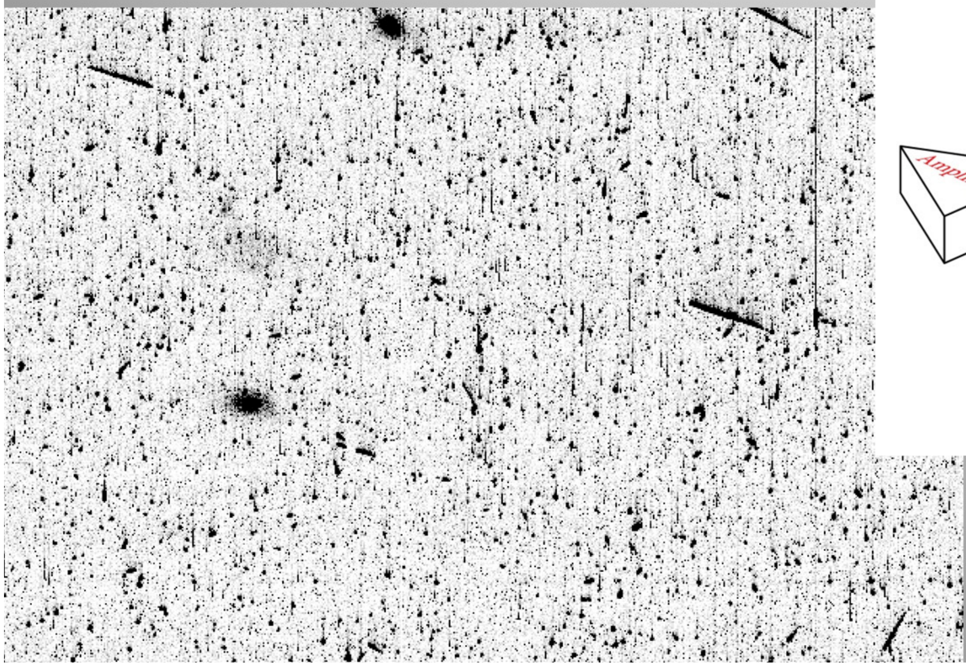
Limit given by Amara and Refregier 2007:

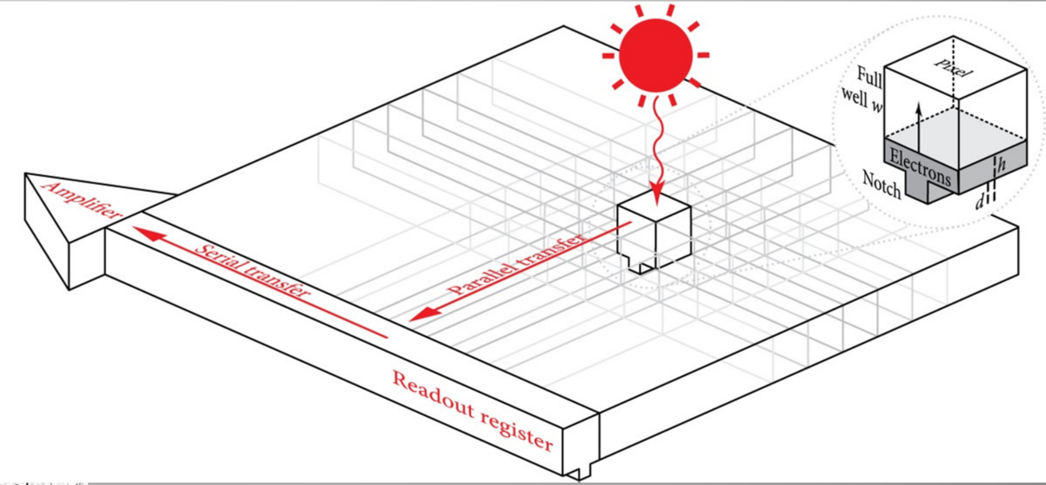
$$\sigma^2(\mathrm{sys}) \leq 10^{-7}$$ (for additive or ‘c’ type errors)

$$m < 10^{-3}$$

CCD Effects - 1

- Charge Transfer Inefficiency (CTI) caused by radiation damage
  - Non linear
  - Does not allow for ‘typical’ WL correction techniques
  - Primary problem with HST (STIS, WFPC2, ACS)
  - *Unmitigated, will cause a space mission to fail to meet requirements*



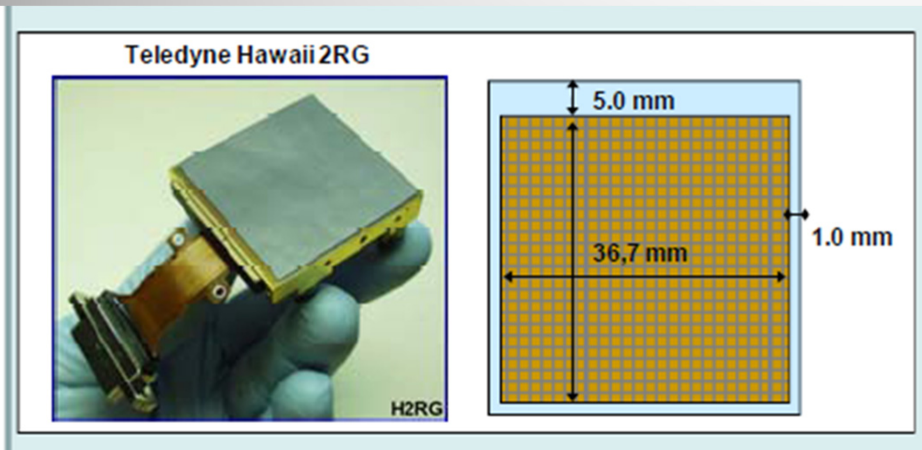


CCD Effects - 2

- Detector non-linearity
    - Conversion of integrated signal to charge (degrades at high signal)

- Reciprocity failure
    - Less signal when it is coming in fast (or vice versa)
    - Exposure time non-linearity
    - Important when comparing bright stars to faint galaxies take with different exposure times

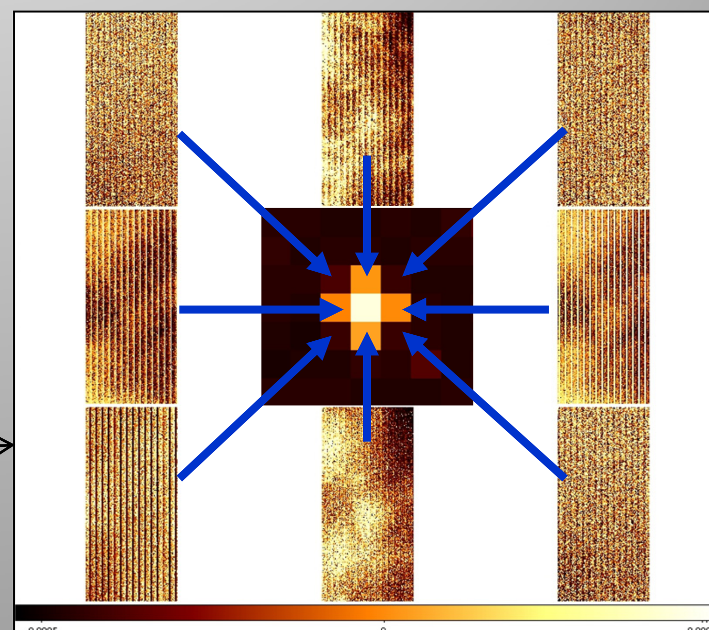
HgCdTe Effects



$$P_n = \beta(x,y)\sum_{i=1}^{10}\alpha(i)\cdot I_{n-i}\cdot e^{-\frac{2.2 I_n}{I_{n-i}}}$$

# frames since stimulus i	Persistence fraction $\alpha(i)$
1	0.2246
2	0.0225
3	0.0085
4	0.0043
5	0.0025
6	0.0016
7	0.0011
8	0.0008
9	0.0006
10	0.0005

- Detector non-linearity
- Reciprocity failure
- Image persistence (or ghosting)
- Interpixel Capacitance
- Individual pixels read out → No CTI



Mitigation Strategy

1. **Model effects through characterization, remove effects in software, and verify with projection system**

2. Change detector/electronics design
   - e.g. more readouts in CCDs

3. Optimize survey strategy.
   - 90 degree rotation for CTI
   - Large dithers for persistence

4. Monitor for changes during mission
   - Especially CTI, through, e.g. pocket pumping
   - Observe standard fields

Strategy 1

- Measure effects (*per pixel*) in the lab
- Develop mathematical models for effects
- Incorporate detector models into simulated images to determine size of effect (only CTI is a serious problem)
- Invert algorithms that add detector effects in order to create algorithms that remove these effects
- Test our removal algorithms on projected images (i.e**. do weak lensing in the lab**)
- Iterate the procedure incorporating improvements in models and algorithms using knowledge gained in previous steps
- Calculate the residual systematics after correction algorithms are applied and give recommendations for detector, electronics, and survey design

This Model Works

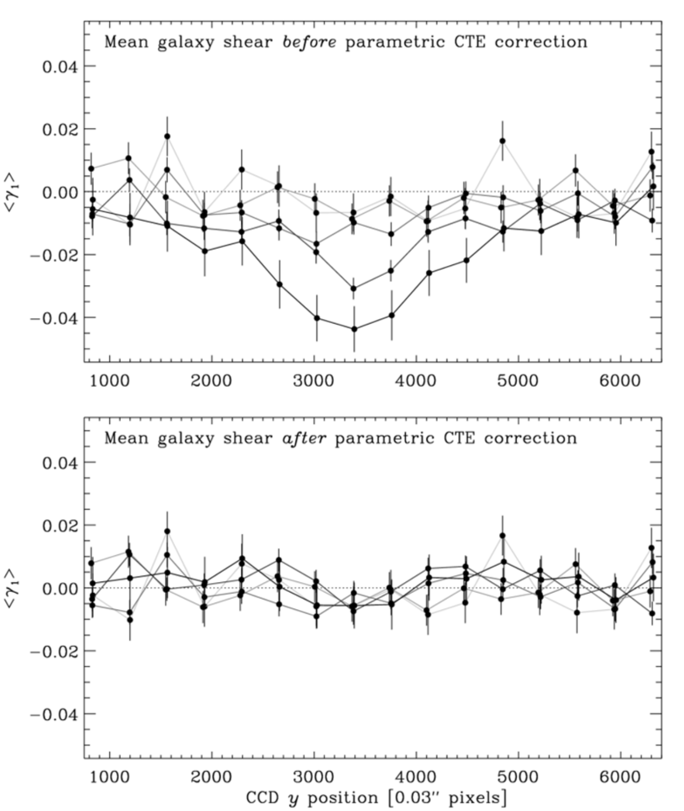
"The Effects of Charge Transfer Inefficiency (CTI) on Galaxy Shape Measurements" Rhodes et al 2010

"Pixel-based correction for Charge Transfer Inefficiency in the Hubble Space Telescope Advanced Camera for Surveys", Massey et al 2010

"Charge transfer inefficiency in the Hubble Space Telescope since Servicing Mission 4" Massey et al 2010

- **We can correct CTI by a factor of 20 in HST/ACS**
- **This will put CTI below required levels for future missions, *but barely so***

CTI Correction



Catalog Level- OK for COSMOS

•Parametrically correct shapes after all other PSF corrections

•Makes assumption about galaxy population (assume galaxy population has zero intrinsic ellipticity on average)

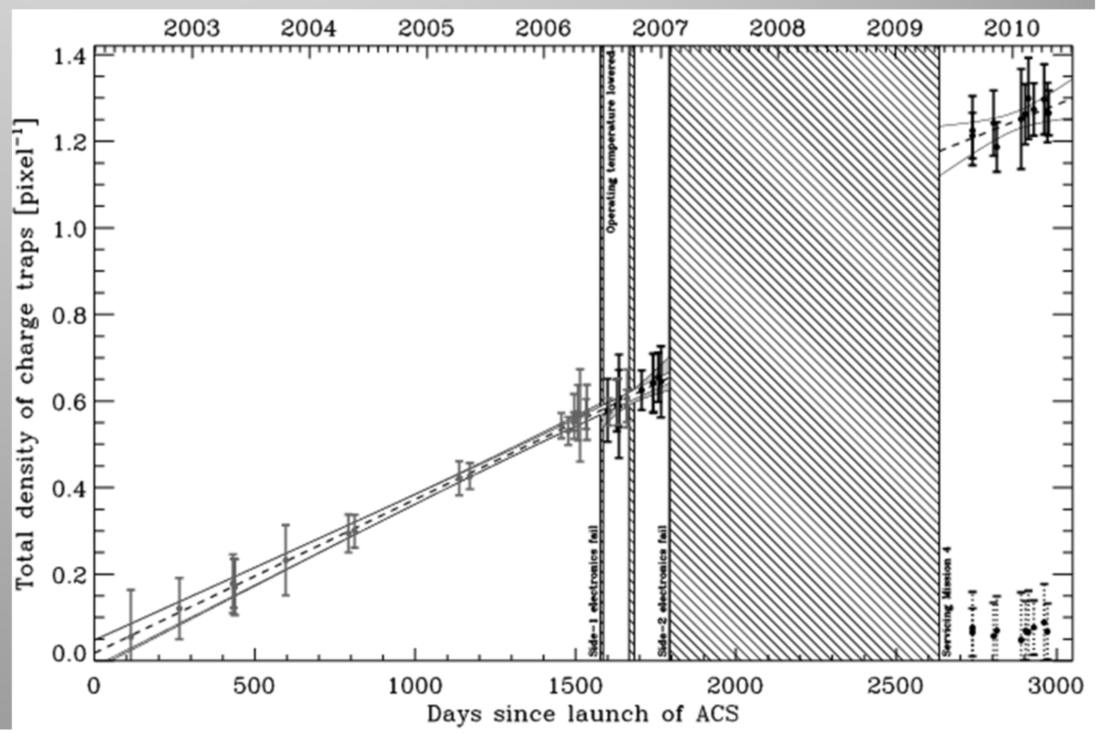
•By definition, effect is zero after correction, but this is degenerate with other PSF

Image Level- MUCH BETTER

•Put charge back where it belongs

•Requires knowledge of trap density, release time

•Allows reduction by a factor of 20



Caveats

- To determine size of effects, we currently just look at Δe(raw)
  - Raw means no PSF deconvolution, just measure weighted moments
  - Non-ideal methods (RRG)

- star/galaxy differences are neglected (different flux regimes)

- So far only bulk effects considered (not variation across detectors)

- IPC is slightly non-linear

Even though effects are smaller than the A&R limit, they add up and are only part of the picture

Simulation vs. Emulation

Simulation: ***computational* analysis of the impact of known effects of real detectors**

Add known detector effects to simulated images

Emulation: ***Experimental*, end-to-end, validation of all sources of systematic errors before and after WL analysis**

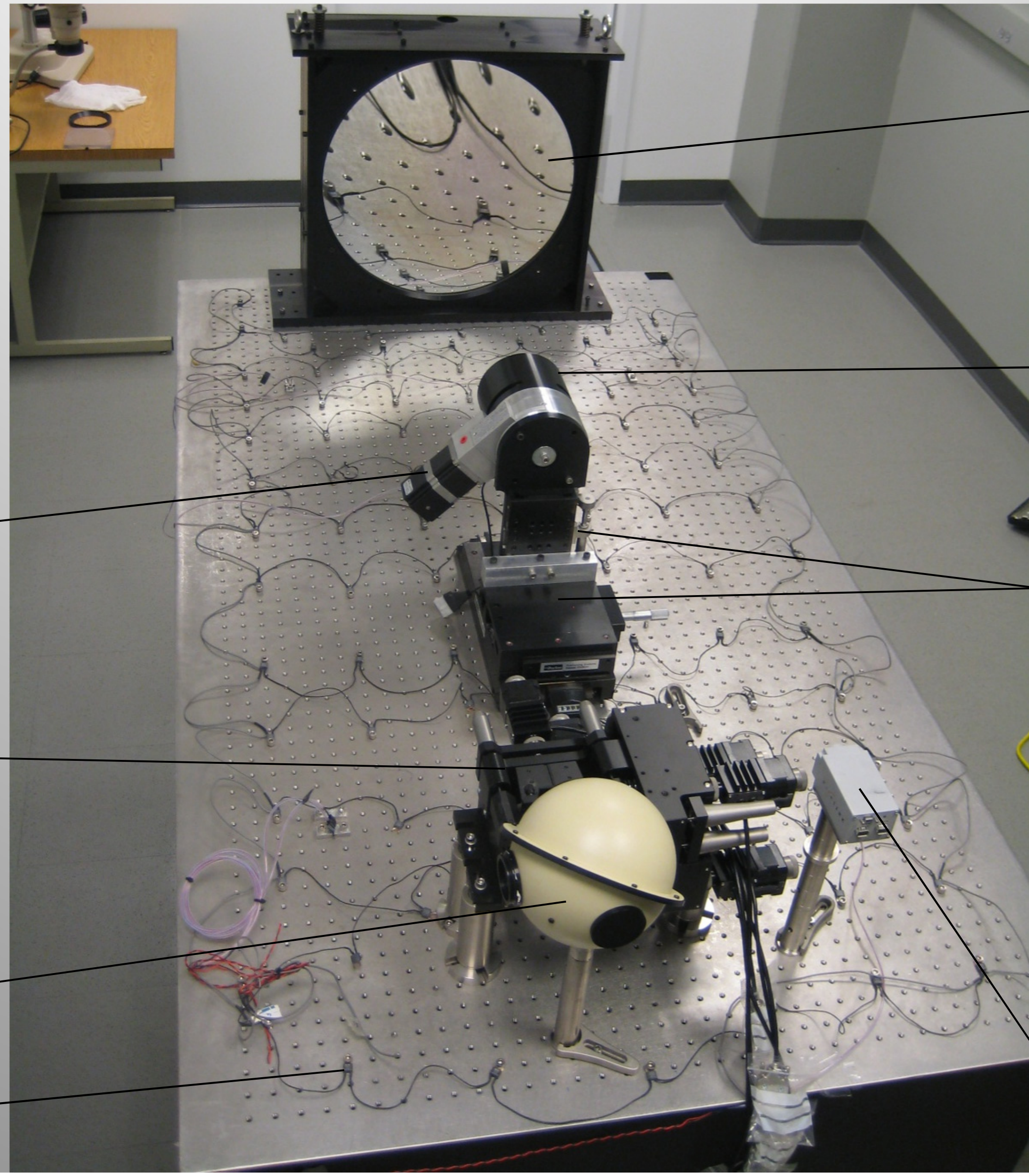
Project known shapes onto detectors
using a range of intensities, PSFs, pixel sampling

Only emulation can uncover the unknown unknowns

Emulation requires a carefully constructed system. We have built such a system at Caltech

Precision Projector

Allows for *emulation* rather than *simulation* of weak lensing experiment



18” primary
RoC=1500mm

4.25” Secondary
RoC=750mm (inside)

Pupil stop rotation motor

XYZ stages for secondary

6 axis flexure stage carrying input mask

Fold mirror, Main camera & enclosure removed, to show optics

Integrating sphere
currently fed by 650nm LED

Alignment camera

Heaters